MATL- 492/892: *Introduction to Quantum Materials and Technologies* (Spring 2022)

Instructor: Dr. Abdelghani Laraoui, W312 NH, email: alaraoui2@unl.edu. Phone: 402.472.7680

1. Communication: Students are encouraged to contact the instructor at any time through canvas and email if having any questions related to the lectures and assignments. Instructor will do his best to reply to all questions in a timely manner. During office hours students can request online meetings via Zoom (https://unl.zoom.us/j/7589487078) or in person meeting following university covid-19 guidelines.

Online/office hours: Wednesday: 1 pm - 3 pm or email for online/in-person appointments.

2. In-person teaching schedule: Lectures will be in person. Following UNL' covid-19 guidelines all students are required to wear face masks.
Date/time: Online and in-person on Tuesdays /Thursdays 12:30pm - 1:45 PM.

3. Course objectives and outcomes:
This is course is designed for (Materials, Mechanical, Electrical, Computer, Biomedical…) engineering, physics, chemistry, and mathematics students (senior undergrads and grads) interested in learning about basics of quantum science and engineering.

Course description:
Wide range of quantum technologies have experienced tremendous growth in the last few years thanks to the progress made in discovering new quantum materials and developing experimental quantum platforms. With claims from IBM and Google of computing exponentially faster than possible classically, quantum computing promises to be a fruitful realization of a new 'unconventional computing' paradigm. In addition, by developing new quantum sensors based on atomic defects in diamond, wide bandgap semiconductors, and two-dimensional materials, wide range of phenomena in physics, biology, and chemistry can be studied at the nanometer scale, leading to new devices and discoveries.

This course introduces basic laws of quantum mechanics and provides an introduction to revolutionary quantum technologies including quantum communications, quantum sensing, and quantum computing. The boundary between classical and quantum physics, quantization of electromagnetic field and its consequences, quantum electromagnetic and atomic physics, quantum topological materials and their applications in quantum technologies are discussed. The course will allow students to develop a conceptual understanding of quantum phenomena and identifies engineering challenges of various quantum technologies.

Learning outcomes:
After completing this course, students will be able to:

- Identify fundamental differences between quantum and classical technologies
- Mathematically describe simple quantum phenomena
- Interpreting quantum signatures in experimental data
- Know about potential quantum materials for improved quantum technologies
- Analyze engineering challenges of quantum technologies
- Learn about research and job opportunities in quantum sciences and engineering

4. Assessment Plan:
Assessments are a combination of quizzes based on multiple-choice questions, homework on summarizing research papers, reading and discussion, as well as a final project.
<u>Quizzes</u> (5- 10 in total) consists of multiple-choice and essay questions.
<u>Homework</u> (5 -10 in total) will be on reviewing and summarizing related-topic papers assigned by the instructor.

Final Project: Students are strongly encouraged to begin designing and developing the final project as soon as possible. Students are expected to perform a case study on a specific quantum technology (for example diamond quantum sensing, bio-quantum sensing, topological materials, quantum communications, etc.) and identify the following components: 1) Motivate and introduction (5%), 2) Basic working principle (25%), 3) Various implementations (15%) 4) Engineering challenges (25%), 5) Ways to mitigate challenges (25%), 6) Conclusion and References (5%).
The final submission can be either in a form of a presentation (30 min) or ~4-page essay. The project can be done only individually. A higher quality of presentation or essay is expected, proportional to the number of participants.

5. Overall Grade:
Final project (60%), quizzes (20%), homework (20%).
The following approximate scale will be used:

A+ >= 95%	A 90-94%	A- 86-89%	B+ 82-85%	
B 78-81%	B- 74-77%	C+ 70-73%	C 67-69%	
C- 65-69%	D+ 60-64%	D 55-59%	D- 50-54%	F <50%

6. Services for Students with Disabilities:
It is my goal that this class be an accessible and welcoming experience for all students. Reasonable accommodations are provided for students who are registered with the Accessibility Services Center and make their requests sufficiently in advance. For more information, contact SSD at 232 Canfield Admin. Bldg, 402-472-3787, acontreras3@unl.edu.

7. Academic honesty:
Academic integrity is of the utmost importance at Nebraska. Be sure you understand expectations of you and your academic work. View the complete list of academic dishonesty violations in the Student Code of Conduct, specifically Article III: Proscribed Conduct, Section B. Conduct – Rules and Regulations, 1. Acts of Academic Dishonesty. For more information, please visit https://studentconduct.unl.edu/.

8. Responsibilities:
- Read the relevant materials in the textbooks before each lecture.
- Study the relevant materials in the textbook/research papers and notes/videos and make an honest attempt at solving the problems/answering the questions.

9. Recommended textbooks:
- Quantum Mechanics with Applications to Nanotechnology and Information Science. Authors: Yehuda Band, Yshai Avishai, ISBN number:9780444537867, 1st edition.
- Quantum Optics: An Introduction. Author: Mark Fox, ISBN number: 9780198566731.
- Quantum Computation and Quantum Information. Authors: Michael A. Nielsen, Isaac L. Chuang, ISBN number: 9781107002173, 10th Anniversary Edition
- Principles of Quantum Computation and Information, Vol I, Basic Concepts, Benenti-Casati-Strini, Publisher: World Scientific Quantum mechanics; a conceptual approach, Publisher: Wiley-Interscience 2004

10. Tentative schedule:

Module	Section	Week
Overview of Quantum Technologies	- Quantum Engineering - Motivation: Quantum Computing - Motivation: Quantum Communication - Motivation: Quantum sensing	1

Fundamentals of Quantum Mechanics	- The Birth of quantum mechanics - Postulates of quantum mechanics - Hamiltonian and Schrodinger Equation - Dirac notation - Density operator	2, 3
Essential Concepts in Quantum Mechanics	- Operators in quantum mechanics - Heisenberg uncertainty - Wave particle duality - Coherence - Entanglement	4,5
Quantum Resources: EM waves	- Quantum EM fields - Polarization of optical fields - EM resonators - Single photon detection - E-field detection - Quantum light	6
Quantum Resources: Cold atoms, quantum dots, defects in diamonds	- Introduction to light-atom interactions - Trapping and cooling atoms - Two-level atom - Spin qubits in quantum dots - Spin qubits in diamond	7, 8
Quantum Resources: Superconducting devices	- Fundamentals of superconductors - Superconducting two-level systems - Superconducting qubits - Superconducting qubits and challenges	9
Quantum Resources: topological materials	- Topological materials: Majorana fermions - Topological materials: Weyl fermions	10
Quantum Sensing	- Ramsey interferometry - Sensing via defects in diamond - Nuclear magnetic resonance pulse sequences: Spin Echo, dynamic decoupling - Biosensing using diamond quantum sensors	11,12
Quantum Communication	- Quantum cryptography - Quantum teleportation - Quantum Memory - Entanglement distribution	13
Quantum computation	- Introduction to quantum computing - Experimental implementation of quantum computation - Deterministic two-qubit logic gates - Quantum logic operations using defects in diamonds - Quantum logic operation using cold atoms - Engineering Quantum Systems	14,15